Comparing and Evaluating Rapid Assessment Techniques of Stream Channel Conditions for Assessing the Quality of Aquatic Habitat at the Watershed Scale

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Abstract
Two rapid assessment methods, both designed to characterize in-stream geomorphic conditions, were applied by two independent field crews to 11 km of the main stream network of the Chico Watershed, located in the Kitsap Peninsula, western Washington State. The purpose of this study was to compare the overall results achieved by the two methods and to evaluate the individual metrics used in each method.

Each methodology was based on four categorical evaluations of channel geomorphology. The "rapid 1" assessment included channel stability, reach complexity, riparian conditions, and cementation; the "rapid 2" method emphasized sediment quality and channel-bank erosion, together with tallies by reach of pools and large woody debris (LWD). The results achieved with each method were evaluated using independent, detailed quantitative measurements that included wood counts and pebble counts, together with estimates of LWD recruitment potential developed from spatial analysis in GIS.

In general, both methods gave similar results. The largest discrepancies appeared at channel gradients higher than 0.02, corresponding to the typical shift from predominantly pool-riffle to typically and step-pool channel morphology. Considering individual metrics in each methodology, channel cementation (common to both schemes) showed statistically different results between the two sets of observers. Bank stability and large woody debris used in the "rapid 2" gave comparable results to channel stability and complexity measured with the "rapid 1" method.

The comparison of these two rapid techniques with the detailed surveying corroborated the findings of ambiguous and highly variable results for cementation. It also showed that rapid LWD counts are a reliable measurement. The riparian condition score, used only by the "rapid 1" using field observations, showed no relationship with the LWD recruitment potential from GIS.

Rapid assessments are entirely adequate to determinate general stream physical condition categories; however, some awareness should be given to the inclusion of variables, such as cementation, that cannot be replicated. Channel-type-dependent metrics can also introduced erroneous classifications. Correlation analysis with biological data is needed to establish if there are functional consequences of these physical discriminations.

Introduction
Two rapid assessments, both designed to characterize current in-stream geomorphic conditions, were applied by two independent field crews to 11 km of the main stream network of the Chico Watershed, located in the Kitsap Peninsula approximately 30 km west of the city of Seattle in western Washington State (Figure 1). The purpose of this study was to compare the overall results achieved by the two methods, as well as the results obtained by individual metrics used in each method. The individual metrics were evaluated in comparison with detailed surveyed data, available for about half of the reaches. The performed evaluations took into consideration the geomorphic context of the surveyed network expressed by their channel type (Montgomery and Buffington 1998) (Segura Sossa in press, 2003).

The assessment of the current in-stream conditions of a watershed is a common part of the agenda of management agencies. These agencies typically experience difficulties in designing and carrying out effective evaluations because of (1) limited time, (2) limited scientific resources, and (3) limited field-staff resources.

While fully quantitative approaches may provide an apparent benefit through their high precision and documentation, they are of limited value if the institutional resources simply do not exist to carry them out (Scholz and Booth, 2001). Repeatability of results across multiple observers is also commonly much poorer than the apparent precision of the raw data might suggest. Finally, management actions commonly occur on a very coarse scale-the range of options is often limited, and even where a high degree of discrimination between different levels of condition might be achieved, the

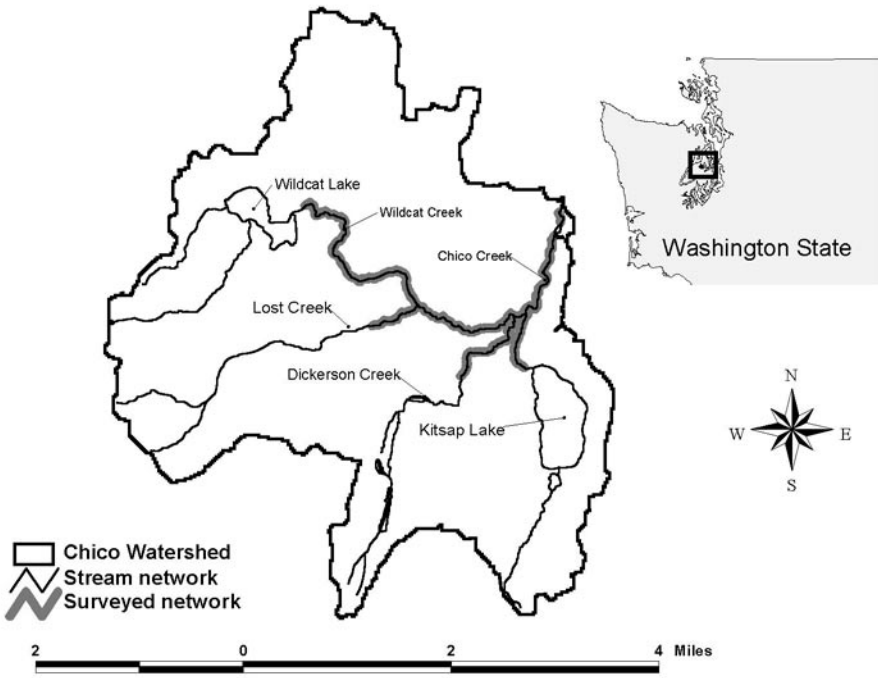

Figure . Location of the study area.

management response to many of those potential outcomes might be identical. As a result, rapid assessment techniques that can cover a channel network rapidly (on the order of miles per day) may provide nearly equivalent benefit to land managers as laborious survey--based techniques, particularly if the rapid approach is calibrated and tested against more precise methods.

Methods

Data sources included the results obtained from 41 reaches surveyed in the main stream network of Chico Watershed by a rapid qualitative assessment ("rapid 1") applied by P. Nelson and M. Rylko, Kitsap County (unpublished data, 2002) and the Physical In-stream Condition Index for the same reaches ("rapid 2 ") (Segura Sossa, in press 2003). Morphologic data from a detailed quantitative survey (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002) and estimates of large woody debris (LWD) recruitment potential, developed from spatial analysis in GIS (Roberts 2003), were also used to evaluate the geomorphic metrics used under each scheme.

Study sites

Study reaches were located in the main stream network of Chico, Wildcat, Lost, Dickerson, and Kitsap creeks (Figure 1). Bedrock underlies the upper sections of the watershed tributaries (Lost, Wildcat, Kitsap and Dickerson creeks); the lower areas are underlain by glacial till, recessional outwash, and advance outwash deposited during the last ice-sheet advance about 15,000 years ago; and some recent alluvial deposits (Haessuler and Kenneth, 2000; revised by D. Booth, written commun., 2002). Chico Creek watershed includes approximately 11 km of in-stream habitat that are accessible to anadromous salmonids. It supports four salmon species (chum, coho, steelhead, and cutthroat trout). Chico Creek's chum population is one of the largest in South Puget Sound, with annual escapements averaging 25,000 adults (T. Ostrom, Suquamish Tribe, unpublished data 2002). The mid-section of the watershed supports important second-growth forest relicts composed by conifer species (*Pseudotsuga menziesii, Tsuga heterophilla,* and *Thuja plicata*) and some hardwood species (*Alnus rubra, Acer macrophyllum*) mainly located in the riparian areas of Wildcat and Lost creeks.

Most of the urbanization in the watershed is concentrated in the lower sections, mainly around Dickerson, Kitsap, and Chico creeks. Total impervious surface area in the watershed, calculated from the 1998 Landsat image using the relative percentages developed by Hill et al. (2003) is approximately 15 %.

Field methods

Both "rapid" assessment techniques were based on the collection of four categorical evaluations of channel morphology. For "rapid 1," analyzed features include channel stability, bed sediment cementation, channel complexity, and riparian condition. For "rapid 2," data were collected to describe bank stability, cementation, and numbers of LWD and pools (Table 1).

Table 1. Metrics considered by each rapid assessment methodology.

"Rapid 1"	"Rapid 2"
Channel stability	Bank stability
Cementation	Cementation
Channel complexity	Pool counts
Riparian condition	LWD counts

Data were collected using reaches as the unit of the survey. The minimum reach length was 20 channel widths in order to capture repetitive patterns of the streams (MacDonald et al 1991; Harrelson et al., 1994; Montgomery and Buffington 1997; Martin, 2001). The break between reaches was established based not only on length but also on natural and anthropogenic divisions, such as change in confinement, tributary confluences, change in condition of the near-riparian zone, and road and railway crossings.

"Rapid 1" Assessment Methodology

Field methods of this technique included the qualitative assessment of 4 geomorphic features. They were based on the protocol by Henshaw and Booth (2000), the Kitsap Peninsula salmonid refugia study (Kitsap County, 2000), the West Kitsap Watershed analysis (WDNR, 1995), the stream channel reference sites (Harrelson et al., 1994), the standard methodology for conducting watershed analysis (Washington forest practices board, 1993), and the summary of channel stability condition categories by Rosgen (2002) (P. Nelson, Kitsap County, personal communication, 2002).

Field data collection took place during the summer of 2002 and was performed by a two-member field crew. The survey included the collection of four geomorphic indicators at the reach scale: Channel stability, reach complexity, cementation, and riparian conditions. Scores for each indicator ranged between 1 and 4 and were assigned based on qualitative comparison between pre-established reference reaches in the Chico Watershed network and after on-site discussion by the crew of key morphology features. Reference reaches with "good" conditions (i.e. individual metric scores = 4) were identified in the mid-section of Wildcat Creek (reaches 2, 8 and 9); each of these reaches received a total score above 14 points. "Poor" reference reaches (metric scores = 1) were located in Chico Creek (reaches 25 through 29) and received total scores below 6 points (Appendix 1).

Channel stability scores were based on visual field indicators of bank stability, channel form, and bedload transport capacity. Bank stability indicators used the classes described by Henshaw and Booth (2000); channel form was assessed by a qualitative evaluation of horizontal stability, vertical stability, and connectivity of the main channel with the floodplain or overflow channels. Bedload transport capacity was evaluated taking into consideration the downstream/upstream routing barriers, available storage capacity, and the extent of upstream sediment inputs (Table 2). The channel stability score was assigned after walking the total length of each reach by selecting the channel stability score (Table 2) that best described the "general" or "average" condition of each reach.

Substrate cementation was measured at one riffle on each reach. The assessment considered the extent of the substrate surface compaction, the extent of surface armoring, and the extent of filled inter-gravel spaces by fine sediment. Scores were given based on the qualitative comparison between the observed conditions at each reach and that registered at the reference reaches (Table 3).

Table 2: Channel stability indicators for "rapid 1" (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002)

Indicators	Score (1 to 4)
Bank stability ▪ perennial vegetation to waterline ▪ exposed fine roots ▪ actively undercutting banks ▪ erosion indicators ▪ bank held by hard points ▪ bank armoring	1: Unstable channel 2: Slightly unstable channel 3: Moderately unstable channel 4: Stable/resilient channel
Channel form ▪ horizontal stability (i.e. width/depth) ▪ vertical stability (aggradation, entrenchment) ▪ connectivity w/ floodplain or overflow channels	
Bedload transport capacity ▪ downstream/upstream routing barriers ▪ available storage capacity (e.g. presence of channel braiding) ▪ extent of upstream sediment inputs	

Table 3. Channel cementation indicators for "rapid 1" (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002)

Indicators	Score (1 to 4)
Extent of substrate compaction	1: Tightly packed bed materials and/or excessive fines 2: Slightly packed bed material 3: Moderately loose bed material 4: Loosely packed bed material with pore space
Extent of substrate surface armoring	
Extent of filling of inter-gravel spaces (in glides) with fines	

Reach complexity was defined by a qualitative visual estimation of the following factors: LWD abundance within the active channel, pool frequency, pool depths, and existence of side channels (Table 4). Scores were assigned after comparing the conditions found at each reach with the conditions observed in the reference sites.

Table 4. Reach complexity indicators for "rapid 1" (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002)

Indicators	Score (1 to 4)
a. LWD abundance within the active channel	1: Non-complex channel 2: Slightly complex channel 3: Moderately complex channel 4: Complex channel
b. Pool frequency	
c. Pool depths	
d. Side channels frequency	

The riparian condition was evaluated in the field in the near-channel area over a width defined by the site-potential tree height or the limit of the active floodplain (whichever was shorter) (Table 5). The following indicators were visually evaluated: degree of shading provided to the channel, existence of multi-aged stands with near-term recruitment potential, presence of conifer species, and the degree of vegetation/soil disturbance in the immediately adjacent land.

Table 5. Reach riparian condition indicators for "rapid 1" (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002)

Indicators	Score (1 to 4)
a. Degree of shading provided	1 Few or no trees in riparian zone 2: Sparse trees in the riparian zone, with few conifers in a moderately disturbed riparian zone 3: Moderately diverse, multi-aged stand, largely dominated by conifers. 4 : Diverse, multi-aged stand dominated by conifers in a undisturbed riparian zone
b. Multi-aged stands with near term recruitment potential	
c. Presence of conifer species	
d. Degree of vegetation/soil disturbance in the immediately adjacent land.	

"Rapid 2" Assessment Methodology

Field methods for this technique were based on the protocol for the monitoring of urbanizing streams first articulated by Henshaw and Booth (2000) and further refined by McBride (2001). Channel surveys of the main channel network of the Chico Watershed occurred during spring and summer 2002 by one field worker. The survey consisted of quantitative and qualitative reach-scale information collected on stream bank condition, substrate condition (cementation), and two components of channel complexity (large woody debris and pool abundance).

Bank stability score for each reach was assigned using the categories defined by Henshaw and Booth (2000) (Table 6). An additional bank stability category was included to describe reaches where banks were consistently armored by artificial structures. This category was given the same score as class 1 (completely unstable) based on the assumption that armoring structures exist as an attempt to stabilize unstable conditions. When the reach was not uniformly in one bank stability class (i.e. neither of them were continually stable, class 4, nor continually armored, class 1), scores were assigned to describe the dominant observed bank condition.

Table 6. Categories of bank stability adapted from Henshaw and Booth (2000) for "rapid 2"

Class	Description
4	STABLE: Perennial vegetation to waterline No raw or undercut banks No recently exposed roots No recent tree falls
3	SLIGHTLY UNSTABLE Perennial vegetation to waterline in most places Some scalloping of banks Minor erosion and/or bank undercutting Recently exposed tree roots rare but present
2	MODERATELY UNSTABLE Perennial vegetation to waterline spare (mainly scoured or stripped by lateral erosion) Bank held by hard points (tree boulders) and eroded bank elsewhere Extensive erosion and bank undercutting Recently exposed tree roots and fine root hairs common
1	COMPLETELY UNSTABLE No perennial vegetation at waterline Bank held only by hard points Severe erosion of both banks Recently exposed tree roots common Tree falls and/or severely undercut tree common
1*	ARMORED BANKS Banks held by placed structures such as boulders, contention walls, etc.

*This category was introduced with the "rapid 2" methodology.

The substrate measure of cementation was performed on a riffle at each reach, gauging the degree to which the channel bed had hardened by pushing a boot heel a few cm into the channel bed. The reaches were ranked according to the criteria used by McBride (2001) (Table 7).

Table 7. Categories of bank substrate cementation (McBride, 2001) for "rapid 2."

Class	Description
4	Excellent: grains easily yield under heel pressure and release little or no sediment plume.
3	Good: grains move with some heel pressure, small sediment plume.
2	Fair: grains yield only with large heel pressure, large sediment plume.
1	Poor: heel cannot be driven into the channel bed without great pressure.

Measures of channel complexity were made for two elements independently, based on full-reach tallies. Woody debris abundance was recorded for each reach, using the minimum criteria of 1 m in length and 25 cm in diameter (Montgomery et al., 1995). Pool abundance for each reach used minimum dimensions dependent in channel size. A "pool" was defined as having a minimum residual depth of 25% of the bankfull depth and a minimum pool length of 10% of the bankfull width (Montgomery et al., 1995).

Large woody debris scores were assigned by reference to the observed ranged of wood counts in the surveyed reaches and taking into consideration a prior study to define regional in-stream wood targets (Fox et al., 2003). LWD counts were divided into four categories based on the 25, 50, and 75 percentiles of the Chico Creek data set: 7, 21, and 33 LWD/100m respectively (Table 8) (Segura Sossa in press 2003). Pool counts, as in the case of LWD counts, were divided into 4 categories based on the 25, 50, and 75 percentiles of the data set: 5, 7, and 8 pools/100m respectively (Table 8). This approach was used in the absence of consensus on suitable pool targets in the literature (Segura Sossa in press 2003).

Table 8. Scoring classes for LWD and pools tallies for "rapid 2."

Parameter	Description	Scoring class			
		1	2	3	4
LWD abundance	Pieces/100m	<7	7 - 21	22 - 33	>33
Pool abundance	Units/100m	<5	5- 7	8	>8

Scoring method
For both "rapid 1" and "rapid 2," each of the four categorical evaluations received a score between 1 and 4 points. This gave a total possible reach score ranging between 4 and 16 points. The total score range was divided into 3 equal bands to display overall reach geomorphic condition: "low quality" for scores between 4 and 8; "intermediate quality" for scores between 9 and 12; and "high quality" for the remaining 13 to 16 points.

The results achieved by each scheme were spatially displayed using the GIS software ArcView 3.2.

Analytical Methods

Analytical methods included spatial comparison of results considering the channel type context, statistical comparison (paired t-test), and regression analysis (Zar 1996, Neter et al., 1996). Both total results and individual metrics of the two methodologies were compared. Some of these individual metrics were contrasted with quantitative detailed information available for 18 reaches (40% of the surveyed reaches) and with an alternative method of LWD recruitment potential developed with GIS analysis (Roberts 2003). SPSS 10.1 statistical software[tm] (SPSS Inc., Chicago IL) was used for the statistical analysis using an alpha level of 0.05.

Channel cementation was the only metric common to both schemes. However, other comparisons could be made based on the similarity of metrics: channel stability from "rapid 1" *v* bank stability of "rapid 2," and the complexity score of "rapid 1" *v* pool counts and LWD counts scores of "rapid 2." The "rapid 2" assessment did not include metrics for riparian conditions; therefore, a comparison between the two schemes was not possible. However, the riparian condition score results from "rapid 1" could be compared to the recruitment potential calculated for each reach using orthophotos, tree height (from LIDAR), and field observations (Roberts, 2003). Recruitment potential was summarized by Roberts (2003) into three categories (high, medium and low) considering species composition, vegetation density, and tree size. In this study, riparian condition ("rapid 1") was contrasted with this LWD recruitment potential for a zone 30 m from each side of the channel.

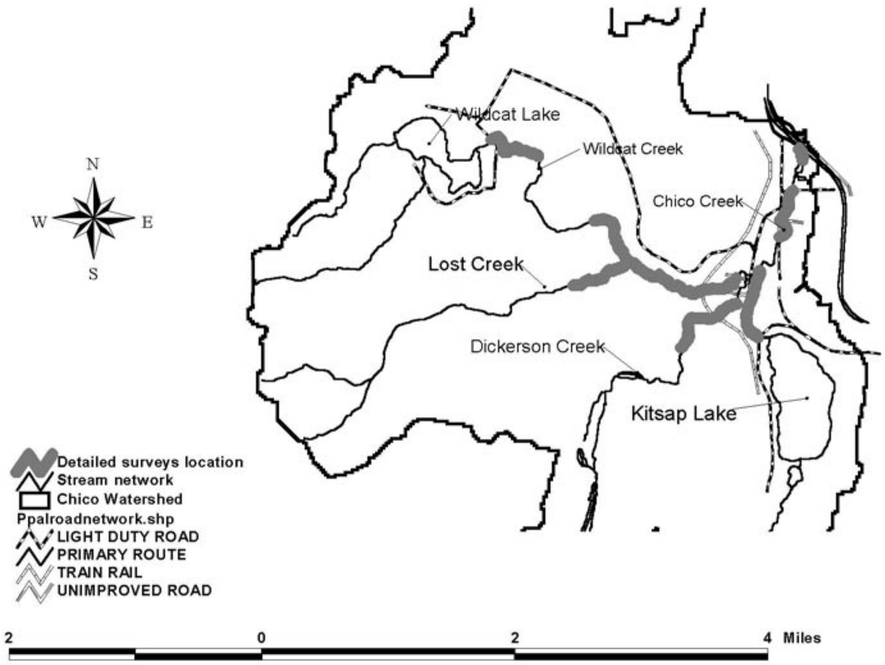

Figure 2. Location of the detailed surveys

Independent, detailed morphologic data for 18 reaches (P. Nelson and M. Rylko, Kitsap County, unpublished data, 2002) permitted an evaluation of some of the metrics considered by the two assessments (Figure 2). Correlation analysis was used to evaluate the relationship between cementation scores and abundance of fine sediment in the channel, using D_{16} calculated from riffle pebble counts as an index of fine sediment abundance. Cementation is a measure of bed sediment compactness, which occurs in the presence of high levels of fines. Finally, wood counts performed as part of these detailed survey but not included in the “rapid 1” assessment were correlated against the wood counts performed as part of the “rapid 2” assessment.

Results

Total Scores Analysis
The overall outcome of the two methods provided similar in-stream geomorphic condition discrimination among the surveyed reaches (Figures 3 and 4). Both rapid assessment methods recognized relatively high-quality physical conditions in the upstream portions of the Chico Watershed tributaries (Wildcat, Lost, and Dickerson creeks) and a pattern of decreasing in-stream physical quality towards the lower sections of the basin. Reaches in the lower sections of Chico, Dickerson, and Kitsap creeks were mainly categorized in the intermediate-and low-quality bands (scores below 12) by both methods (Figures 3 and 4).

The scores averaged for all reaches along each individual creek were very similar in all streams for both methods, except in Kitsap Creek. According to both schemes, Wildcat and Lost creeks are within the highest category (scores 13-16); Dickerson Creek is within the intermediate category (scores 9-12); and Chico Creek is within the lowest category (scores 4-8). Kitsap Creek, which had on average the highest discrepancies between the method on individual reaches, was intermediate under the “rapid 2” assessment and in the lowest category by the “rapid 1”assessment (Figure 5).

Total scores were graphically compared across the surveyed reaches in terms of both the difference between total scores assigned by each methodology and the difference in the number of reaches classified among physical condition categories by each scheme. The absolute discrepancies between total scores assigned by each methodology were below 3 points at 32 reaches (78%). At four reaches (10%) the difference between total scores was 3 points, and at the remaining 5 (12%) the differences were above 3 points (Figure 6). The distribution of the surveyed reaches among the defined categories showed similar outcomes in regards to reaches classified at the highest level, but variable results for reaches into the two lower categories. In other words, the methods are most consistent in identifying the best reaches (Table 9).

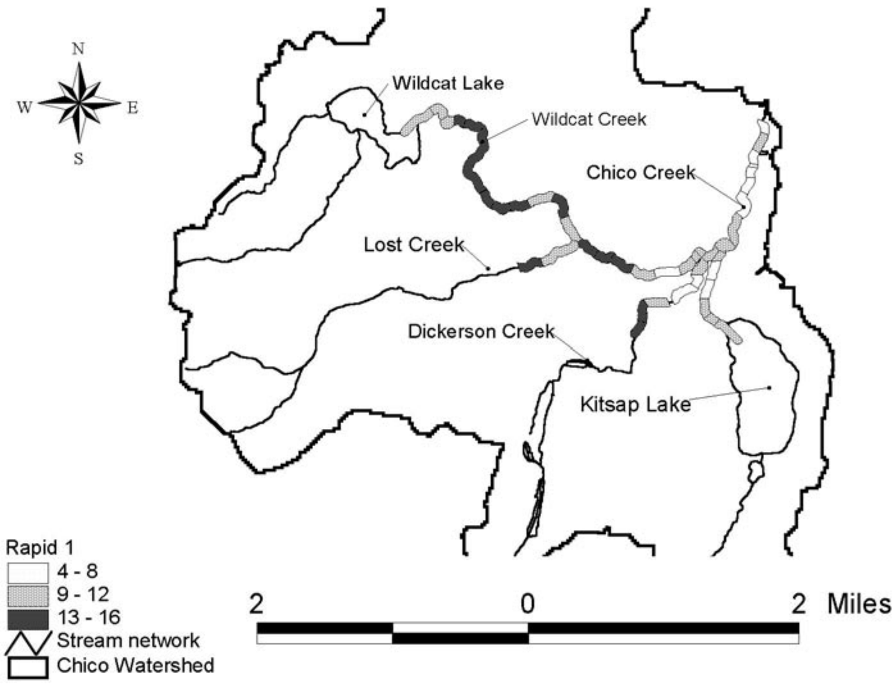

Figure 3: Geomorphic characterization by the "rapid 1" method.

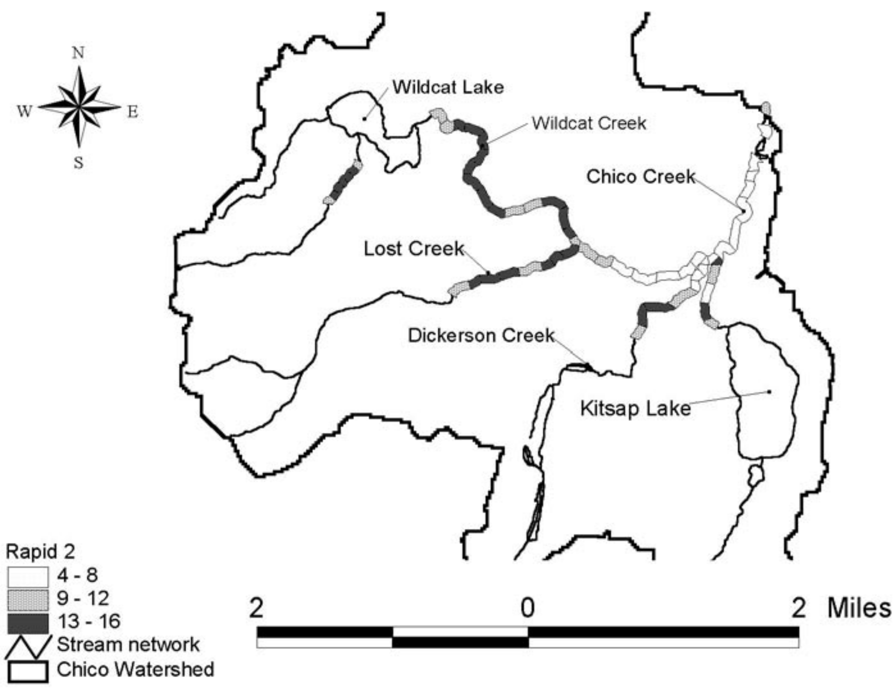

Figure 4: Geomorphic characterization by the "rapid 2" methods.

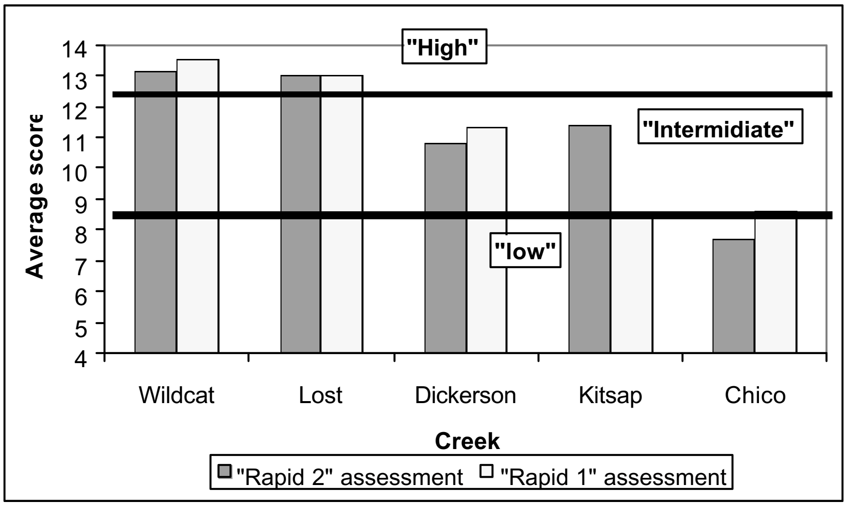

Figure 5. Average results per creek for both rapid assessment methodologies.

Table 9. Number of reaches classified into each physical quality category by both rapid assessment methodologies.

Physical quality	Rapid 1	Rapid 2	Difference (%)
High (13-16 points)	14	12	14
Intermediate (9-12 points)	16	12	25
Low (4-8 points)	11	17	50

The channel type of the 5 reaches (reaches 19, 21, 23, 31 and 39) where discrepancies were above 3 points suggests that the correspondence of the two methods, in terms of comparability, decreases at channel types with gradient above 0.02 and at reaches where the natural morphology has been altered by anthropogenic influence (Figure 6 and Appendix 1). Channel types of three out of these five reaches were registered at slopes above 0.02 (reaches 19, 21, and 23). Reach 31 corresponds to a "constrained" pool-riffle type (i.e. low gradient channel in which the stream is isolated to the floodplain by the placement of artificial armoring structures). Reach 39 corresponds to a forced pool-riffle (FPR) with a gradient of 0.01 and no obvious direct anthropogenic influence.

An R^2 of 0.57 was found between the total results (Figure 7). A paired t-test of the total scores indicated that the mean difference between total scores is 0.2 points, not significantly different throughout the sample ($p = 0.59$). The linear regression between the total scores indicated a significant relationship between the two measurements ($F = 51$, $p <0.00$); and a slope of 0.8 (nearly a 1-to-1 relationship, with a slight tendency for "rapid 1" scores to be higher) (Figure 7).

The channel type of the 4 reaches above 1.5 standard deviations from the fitted regression line between total scores (Figure 7, right) emphasized the decreasing correspondence between the two methodologies at slopes above 0.02. Three of these 4 reaches had slopes above 0.02: 1 cascade (reach 19) and 2 FPR (reaches 21 and 23). The fourth reach was a FPR with a slope of 0.01.

Analysis on IndividuaMetrics

Individual metrics used in each methodology were analyzed in terms of the coefficient of determination between similar pairs of metrics from both techniques (Table 10 and Figure 8). In addition, a paired t-test was used to evaluate the null hypothesis of equal mean difference between a given pair of similar scores (Table 11).

The analysis of the individual metrics considered by the two techniques indicates that both bank stability ("rapid 2") and channel stability ("rapid 1") gave similar results to the surveyed reaches ($R^2 = 0.71$). Cementation scores assigned by the two methodologies provided different scores to the analyzed reaches ($R^2 = 0.03$). Channel complexity ("rapid 1") was found to be related with LWD counts ("rapid 2") ($R^2 = 0.41$). However, essentially no relationship was found between channel complexity ("rapid 1") and pool counts ("rapid 2") ($R^2 = 0.16$) (Table 10 and Figure 8).

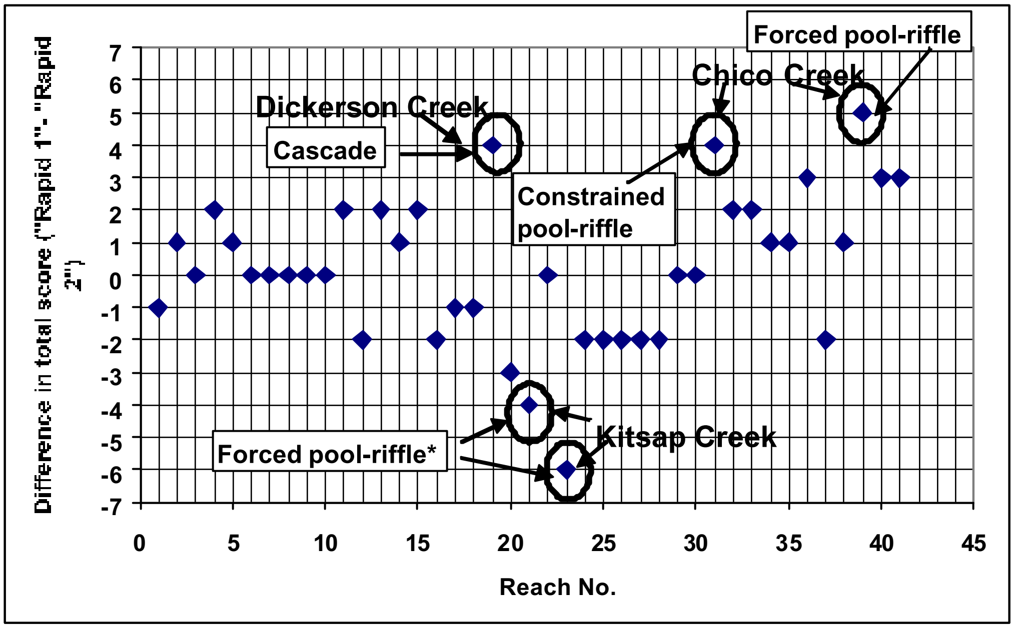

Figure 6. Differences of total scores between the two methodologies. Differences between total scores higher than 3 points are highlighted; *:forced pool-riffle reaches at slopes above 0.02.

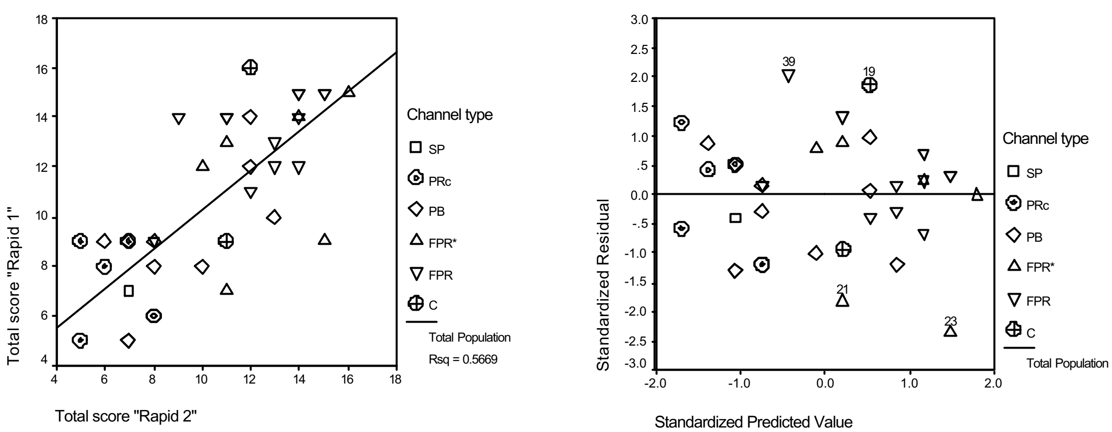

Figure 7. Scatter plot (left) and residuals plot (right) of the relationship between total results of the two methodologies.

Table 10. Coefficient of determination (R^2) between similar metrics.

	Metric	"Rapid 2"			
		Bank stability	Cementation	Pools	LWD
"Rapid 1"	Channel stability	0.71			
	Cementation		0.03		
	Channel complexity			0.16	0.41

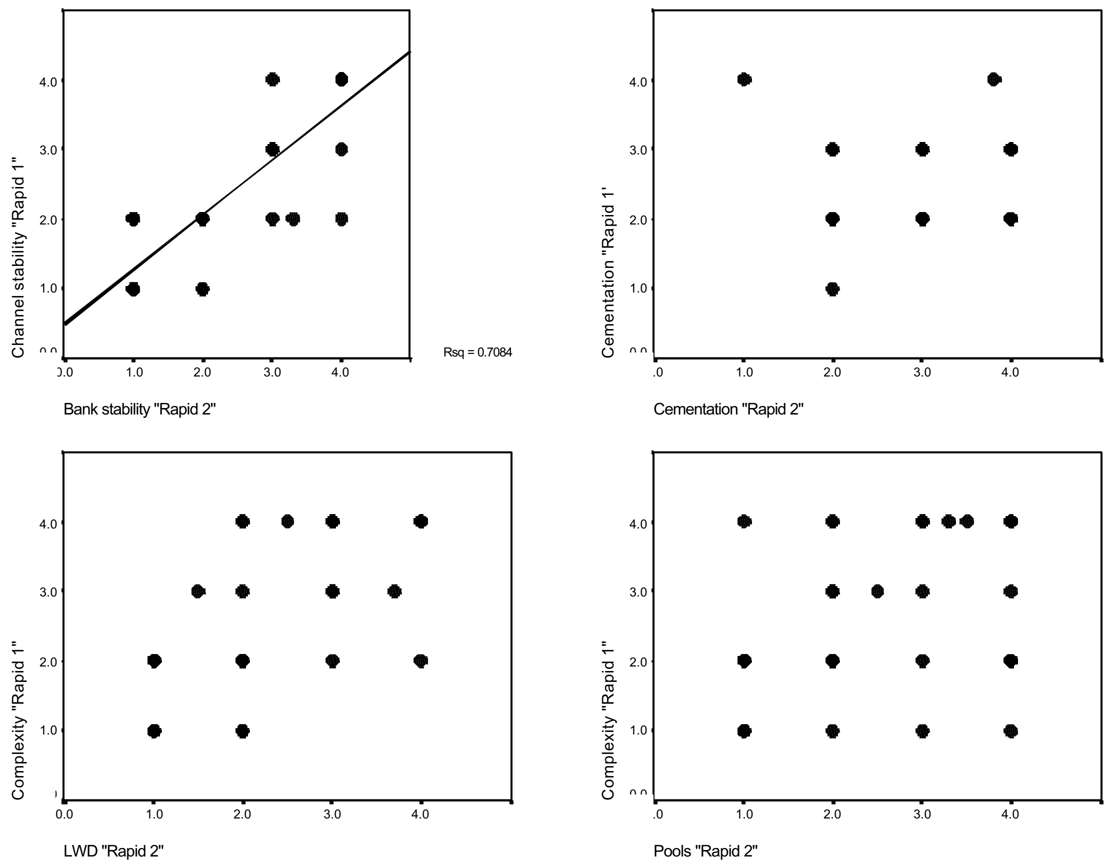

Figure 8. Scatter plots of similar metrics from the rapid assessments.

Table 11. Paired t-test of differences between total scores and individual metrics.

Pair	Variables	Paired Differences		t	df	Sig
		Mean	Std. Deviation			
1	Total score “rapid 2” - Total score “rapid 1”	-0.20	2.28	-0.55	40	**0.59**
2	Bank stability “rapid 2” - Channel stability “rapid 1”	0.06	0.60	0.60	40	**0.56**
3	Cementation “rapid 2” - Cementation “rapid 1”	0.39	0.89	2.76	40	0.01
4	LWD “rapid 2” - Complexity “rapid 1”	-0.32	0.89	-2.33	40	0.03
5	Pools “rapid 2” - Complexity “rapid 1”	-0.19	1.20	-1.00	40	**0.32**

No statistically significant differences were found between either bank and channel stability scores nor between pools and complexity scores. Conversely statistically significant differences were found between both cementation scores and LWD and complexity scores (Table 11). Mean difference between similar pairs of metrics were found to be as high as 0.39 points (cementation scores) and as low as 0.06 points (bank and channel stability) (Table 11). Bank stability and channel stability gave the same score to 73% of the surveyed reaches (30 reaches); cementation metrics scored equally 20 reaches (44% of the sample); LWD and complexity scores were the same at 20 reaches (46% of the reaches); and LWD and pool metrics gave the same score to 17 reaches (34% of the reaches) (Table 12).

Table 12. Differences between scores for similar metrics of the rapid assessments.

Difference	Bank and channel stability	Cementation scores	LWD and complexity	LWD and pools
0	30	20	20	17
1	10	11	17	16
2	1	9	4	6
3	0	1	0	2

The analysis of the relationship between riparian condition score, included in the "rapid 1" assessment, and LWD recruitment potential (Roberts, 2003) in the 30-m riparian area, showed no significant relationship ($R^2 = 0.08$). This indicates that the riparian condition score does not capture the same information than the LWD recruitment potential from GIS analysis. It is likely that the riparian condition score represents the condition of the-near-riparian zone that can be visually assessed from the channel, which may vary from reach to reach, whereas the LWD recruitment potential describes the condition of a near-riparian area more uniformly across all the surveyed reaches.

Comparison of the individual metrics suggests that:

- Bank stability ("rapid 2") and channel stability ("rapid 1") provide similar results.
- Cementation scores measured by both methods are consistently unrelated.
- The relationship between LWD counts ("rapid 2") and complexity ("rapid 1") is strong ($R^2 =0. 42$).
- The relationship between complexity ("rapid 1") and pool counts ("rapid 2") is weak ($R^2 = 0.16$).
- The riparian condition score ("rapid 1") does not describe the LWD recruitment potential from GIS analysis.

Evaluation of Individual Metrics Using Detailed Geomorphic Data

The accuracy of metrics used by the two methods was evaluated based on detailed information for 18 of the 41 reaches (Figure 2, Appendix 1). Cementation scores from either of the two rapid methods were not related with the measured D_{16}. Tallies of LWD ("rapid 2") and the complexity scores ("rapid 1") were significantly related with the LWD counts of the detailed surveys (Table 13).

Table 13. Coefficient of determination (R^2) between metrics from the rapid assessment methodologies and data from detailed surveys.

Rapid assessment metrics	Detailed surveys	
	D_{16}	LWD /100
Cementation ("rapid 1")	0.05	
Cementation ("rapid 2")	0.02	
LWD/100m ("rapid 2")		0.61
Channel complexity ("rapid 1")		0.50

A strong relationship was found between both LWD/100 from the "rapid 2" assessment and the complexity score ("rapid 1") and LWD/100 from detailed geomorphic surveys, $R^2 = 0.61$ and 0.5, respectively (Table 13 and Figure 9).

Discussion

According to the results, the contrasted methodologies lost robustness at channel gradients higher than 0.02, which corresponds to the typical shift from predominantly pool-riffle channels (at gradients below 0.02) to forced pool riffle (FPR) and cascade channels (identified at gradients above 0.02) in the surveyed network.

Bank stability and channel stability are both qualitative metrics that provide the same discrimination among the surveyed reaches ($R^2 = 0.71$ $F= 94.76$, $p= 0.00$). However, because the bank stability metric of "rapid 2" only considered the evaluation of one attribute (stability of the banks) it probably makes that scheme easier to apply.

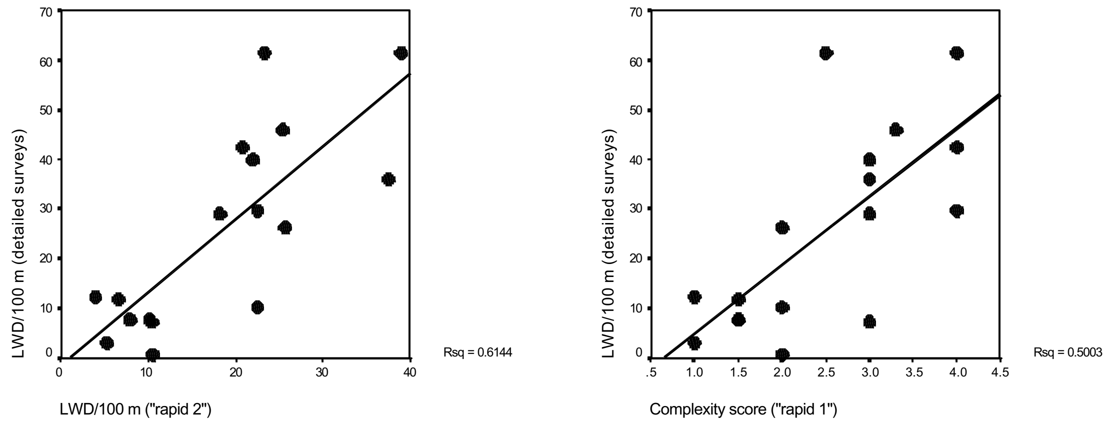

Figure 9, left. Scatter plot of the relationship LWD counts from the detailed surveys and the “rapid 2”. Right: Scatter plot of the relationship LWD counts from the detailed surveys and channel complexity (“rapid 1”).

Channel cementation metrics provided ambiguous results. Cementation is a metric developed to describe the compactness and hardness of a riffle substrate, which is largely a result of silt and clay intrusion into the interstices of a gravel bed (McBride 2002). The fact that cementation scores (by either crew) were not related to D_{16} indicated that it did not actually capture the condition what it was designed for. This metric was (1) not comparable between two set of observers and (2) not a good predictor of fine sediment in the channel bed.

LWD counts (“rapid 2”) and channel complexity (“rapid 1”) provided similar discrimination among the surveyed network. Discrepancies, which were never above 2 points, are likely to be related both to the natural variability of the measurements and to differences in the geomorphic indicators considered by each metric. Channel complexity incorporates the evaluation of other indicators in addition to in-stream wood (pools and side channels frequency) and is dependent on the features observed at a particular channel type (reference reaches).

Since LWD counts and channel complexity scores provided the same overall discrimination for the surveyed reaches, either one could presumably be used. However, the transferability of the LWD counts was tested and confirmed with results from an independent detailed survey. Furthermore, LWD are easier to measure because they only require the field crew to do one task, collecting tallies of LWD. Channel complexity, on the other hand, requires the field crew to have a qualitative sense of the amount of wood and the frequency of pools and side channels in relation to predetermined reference conditions, which requires special training and experience together with a high degree of subjective judgment.

The relationship between pool counts (“rapid 2”) and channel complexity (“rapid 1”) showed a weak relationship, most likely because channel complexity is a channel-type-dependent metric. “Good” channel complexity conditions are naturally different, depending on channel type. Considering in-stream wood and pool frequencies as surrogates for complexity, Montgomery et al. (1995) reported variable pool spacing values for different channel types in Alaska and Washington. According to their study, forced pool-riffle channel have more pools than step-pool and plane-bed channels, and they also have relatively more pools formed by LWD. Since the “rapid 1” assessment assigned complexity scores based on reference conditions that were uniformly at FPR channels in this watershed, scores assigned to other channel types will tend to be “low,” implying that this metric is not transferable across all channel types observed in the Chico Watershed network. Even though pool counts (“rapid 2”) is also a channel-type-dependent metric, it provided a quantitative approach based on a tailed of a unique feature, not biased by expected conditions registered at a particular channel type.

The riparian condition metric, used only by the “rapid 1” as an in-stream estimate of corridor vegetation density, showed no relationship with the LWD recruitment potential calculated from GIS (Roberts, 2003). Riparian condition visually assessed from the channel is likely to be dependent on site conditions that may limit the extent of the riparian area that can be visually assessed during the survey. As an example, Figure 10 shows the LWD recruitment potential displayed from GIS (Roberts, 2003) compared to the riparian area as observed from the channel. This reach, located in Kitsap Creek, was given a riparian score of 3, whereas only 19% of the 30-m riparian zone was classified in the high LWD

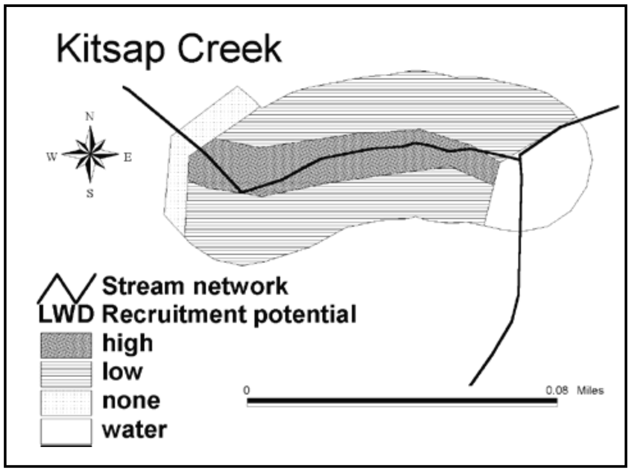

Figure 10. Contrast between riparian condition metric and LWD recruitment potential. Left, LWD recruitment potential calculated in GIS; right, riparian zone in the same reach as it is observed from the channel.

recruitment potential category. Discrepancies as the one illustrated in Figure 10 are likely to be the common denominator of the surveyed reaches. A field assessment of the riparian area can provide more detailed and refined information than the GIS approach, but it would not be rapid since it requires observations outside of the channel (i.e. vegetation plots or transects). The GIS approach provided an easy, rapid alternative to broadly discriminate among reaches.

The ranges of total scores used to discriminate the channel network into “low,” “intermediate,” and “high” physical conditions should be only interpreted in context of what they are: a discrimination solely in terms of the physical condition. Correlation analysis of the rapid assessment results with biological data (e.g. fish surveys or benthic macroinvertebrates communities) would be required to establish whether or not these physical condition categories have any meaning in terms of the biological condition of the streams.

In an attempt to find some functional connotation of the results obtained with the “rapid 2” assessment, a comparison of the metrics included in that method was made with the conditions described in the Matrix of Pathways and Indicators (NMFS, 1996) for evaluating the effects of human activities on anadromous salmonid habitat.

In-stream wood and pool frequency criteria in the NMFS matrix indicate that “properly functioning” conditions are associated with more than 4.7 wood pieces of at least 0.6 m in diameter and 15 m in length per 100 m, and pool frequencies between 2 and 3 pools per 100 m with a minimum pool depth of 1 m. Wood and pool counts for “rapid 2” considered minimum dimensions documented for similar stream size in the region (Montgomery et al. 1995), but the size criteria for both are much smaller than the one used in the NMFS matrix. Therefore, the application of the NMFS criteria to our results is not possible.

According to the NMFS matrix, most if not all of the surveyed reaches in Chico would be associated with “not properly functioning conditions” with regards to bank stability. The matrix criteria defines reaches with “functioning conditions” to have over 90% of the banks in stable conditions; “at risk” reaches have between 80 and 90% stable banks. Over two-thirds of the reaches at Chico would be in “not properly functioning” category , because reaches with bank stability scores below 4 points have more than 80% of their bank length eroded.

Since correlations between our results and the NMFS matrix were not conclusive, further analysis of the rapid assessment in relation to biological measurements will be necessary to establish if the physical condition categories used by the assessment have any relationship to the functionality of the surveyed reaches. Chico Creek reported chum population with annual escapements averaging 25,000 adults (one of the largest in South Puget Sound); therefore, Chico clearly must have some “functioning” sections. The results of this study are insufficient to determine if the physical conditions as described appropriately identify their location in the watershed.

Despite these limitations, we believe that our results show that rapid assessment methods are justified wherever a limited number of management options are being considered. For many jurisdictions, the overriding need is for identifying a few general categories of stream condition; typically, the management responses will be to protect those streams that have "good" conditions, to maintain and/or rehabilitate those that are showing some signs of impairment, and to acknowledge the need for future, intensive remedial actions for those that are already significantly degraded by human action. Where intensive rehabilitation work is planned, detailed quantitative assessments ultimately will be needed. To include such measurements as part of a preliminary regional assessment, however, makes little sense.

Conclusions

- The categorical results of the two assessment methodologies were the same at more than three-quarters of the surveyed reaches. The largest discrepancies occurred almost exclusively at reaches with slope above 0.02, implying that the reliability of such geomorphic metrics are dependent on channel type.

- In general, discrepancies between the two methods are largely a result of the use of reference reaches for "rapid 1" that were uniformly in channel types with gradient below 0.02 (reference reaches).

- Measurements of bank stability are particularly robust, yielding similar discriminations among the surveyed network for the two methods.

- Measurements of channel cementation, common to both schemes, are apparently not a useful metric, showing statistically different results between the two sets of observers and no relationship with the amount of fine sediments in the channel.

- Tallies of LWD from the "rapid 2" were statistically comparable to both channel complexity ("rapid 1") and to the detailed surveys.

- Only a weak relationship was found between pool counts ("rapid 2") and channel complexity ("rapid 1").

- The riparian condition metric ("rapid 1") showed only a weak relationship with LWD recruitment potential calculated from GIS analysis.

- Rapid assessments are entirely adequate to determinate general stream physical condition categories. However, caution should be apply to: (1) the inclusion of variables, such as cementation, that cannot be replicate and (2) the used of channel-type-dependent metrics.

- Correlation analysis of the rapid assessment result and biological data, such as fish surveys and biological indexes (i.e. BIBI), would have to be included to establish if there are functional consequences of these physical discriminations.

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Paul Nelson and Michael Rylko provided the results for the "rapid 1" assessment and the results of the detailed surveyed for 18 reaches of the Chico Watershed. Mindy Roberts provided the results for the LWD recruitment potential.

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Appendix 1. Channel geomorphic assessment results by each rapid assessment methodology.

REACH No.	Channel type	CEM*	CS*	COMP*	RC*	TOTAL*	CEM**	BS**	LWD**	POOL**	TOTAL**	LWD/100 ** (m)	LWD/100 ***(m)	D_{16}*** (mm)
1	**FPR**	3.0	2.0	3.0	3.0	**11.0**	4.0	4.0	1.5	2.5	12	**10.4**	7.2	17.9
2	**FPR**	3.0	4.0	4.0	4.0	**15.0**	4.0	4.0	2.5	3.5	14	**22.5**	29.7	7.7
3	**FPR**	3.0	3.0	4.0	3.0	**13.0**	3.0	3.0	3.0	4.0	13	**28.8**		
4	**FPR***	3.0	3.0	4.0	3.0	**13.0**	3.0	3.0	2.0	3.0	11	**19.8**		
5	**FPR**	3.0	4.0	4.0	4.0	**15.0**	3.0	4.0	4.0	3.0	14	**37.8**		
6	**FPR**	3.0	4.0	4.0	4.0	**15.0**	4.0	4.0	4.0	3.0	15	**76.5**		
7	**FPR**	4.0	4.0	4.0	3.0	**15.0**	3.8	4.0	4.0	3.3	15	**49.8**		
8	**FPR***	3.0	4.0	4.0	3.0	**14.0**	4.0	4.0	3.0	3.0	14	**25.6**	42.4	11.6
9	**FPR**	3.0	4.0	4.0	3.0	**14.0**	4.0	4.0	2.0	4.0	14	**16.5**		
10	**PB**	3.0	3.0	3.0	3.0	**12.0**	3.0	4.0	3.0	2.0	12	**21.1**	29.0	17.5
11	**FPR***	3.0	3.0	3.0	3.0	**12.0**	3.0	3.0	2.0	2.0	10	**14.9**		
12	**FPR**	3.0	2.0	3.0	4.0	**12.0**	4.0	3.3	3.7	3.0	14	**37.5**	36.0	12.4
13	**PB**	3.0	4.0	3.0	4.0	**14.0**	4.0	3.0	3.0	2.0	12	**21.9**	39.8	9.2
14	**PB**	2.0	2.0	2.0	3.0	**9.0**	4.0	2.0	1.0	1.0	8	**4.0**		
15	**PRc**	2.0	1.0	2.0	3.0	**8.0**	3.0	1.0*	1.0	1.0	6	**1.5**		
16	**PB**	2.0	1.0	2.0	3.0	**8.0**	3.0	2.0	2.0	3.0	10	**16.0**	61.5	
17	**FPR**	3.0	3.0	3.0	3.0	**12.0**	3.0	3.0	3.0	4.0	13	**31.3**		
18	**FPR***	3.0	4.0	4.0	4.0	**15.0**	4.0	4.0	4.0	4.0	16	**46.1**	61.5	9.3
19	**C**	4.0	4.0	4.0	4.0	**16.0**	1.0	4.0	3.0	4.0	12	**28.1**		
20	**PB**	2.0	3.0	2.0	3.0	**10.0**	3.0	3.0	3.0	4.0	13	**22.5**	10.3	
21	**FPR***	2.0	2.0	1.0	2.0	**7.0**	3.0	2.0	2.0	4.0	11	**8.5**	11.8	
22	**SP**	2.0	2.0	1.0	2.0	**7.0**	3.0	2.0	1.0	1.0	7	**4.7**		
23	**FPR***	2.0	2.0	2.0	3.0	**9.0**	4.0	3.0	4.0	4.0	15	**33.9**	26.3	
24	**C**	2.0	2.0	2.0	3.0	**9.0**	3.0	2.0	2.0	4.0	11	**14.2**		
25	**PRc**	1.0	2.0	1.0	2.0	**6.0**	2.0	1.0*	2.0	3.0	8	**10.5**	0.7	34.1
26	**PRc**	2.0	1.0	2.0	1.0	**6.0**	3.0	1.0*	2.0	2.0	8	**7.5**		39.0
27	**PRc**	2.0	1.0	2.0	1.0	**6.0**	3.0	1.0*	2.0	2.0	8	**7.5**		
28	**PB**	2.0	1.0	1.0	1.0	**5.0**	2.0	2.0	1.0	2.0	7	**3.9**	12.2	16.6
29	**PRc**	2.0	1.0	1.0	1.0	**5.0**	2.0	1.0*	1.0	1.0	5	**0.0**	3.1	21.5
30	**PB**	2.0	2.0	2.0	2.0	**8.0**	2.0	2.0	2.0	2.0	8	**8.3**		
31	**PRc**	3.0	2.0	2.0	2.0	**9.0**	2.0	1.0*	1.0	1.0	5	**1.1**		
32	**PRc**	3.0	2.0	2.0	2.0	**9.0**	3.0	1.0*	2.0	1.0	7	**8.4**		

Appendix 1 continuation

REACH No.	Channel type	CEM*	CS*	COMP*	RC*	TOTAL*	CEM**	BS**	LWD**	POOL**	TOTAL**	LWD/100 ** (m)	LWD/100 ***(m)	D_{16} ***
33	PB	3.0	2.0	2.0	2.0	**9.0**	3.0	2.0	1.0	1.0	**7**	2.0		
34	FPR	3.0	2.0	2.0	2.0	**9.0**	3.0	2.0	1.0	2.0	**8**	6.4		
35	FPR	3.0	2.0	2.0	2.0	**9.0**	3.0	2.0	1.0	2.0	**8**	6.4		
36	PB	2.0	2.0	2.0	3.0	**9.0**	2.0	1.0	2.0	1.0	**6**	8.4	7.7	11.3
37	PB	2.0	1.0	1.0	1.0	**5.0**	3.0	1.0	2.0	1.0	**7**	7.4	7.7	15.7
38	FPR	3.0	2.0	2.0	2.0	**9.0**	2.0	2.0	2.0	2.0	**8**	12.6		
39	FPR	3.0	3.0	4.0	4.0	**14.0**	3.0	3.0	2.0	1.0	**9**	10.9	45.8	8.1
40	FPR	3.0	3.0	4.0	4.0	**14.0**	3.0	3.0	3.0	2.0	**11**	32.8		
41	FPR	3.0	3.0	4.0	4.0	**14.0**	2.0	3.0	4.0	2.0	**11**	36.3		

Channel type: PRc: Constrained pool-riffle; FPR: Forced pool-riffle; FPR*: Forced pool-riffle at gradients above 0.02; PB: Plane-bed; SP: Step-pool; C: Cascade.

Scores "rapid 1" assessment: CEM* (cementation), CS* (channel stability), COMP* (channel complexity), RC* (riparian condition), TOTAL* (total score)

Scores "rapid 2" assessment: CEM**(cementation), BS** (bank stability), LWD** (large woody debris counts), POOL** (pools counts), TOTAL ** (total score), LWD/100** (large woody debris per 100m)

Detailed geomorphic surveys: LWD/100*** (large woody debris per 100m), D_{16}***